BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D. C. 20024

B70 08069

SUBJECT: Manual TLI in Apollo 14
Case 310

DATE: August 31, 1970

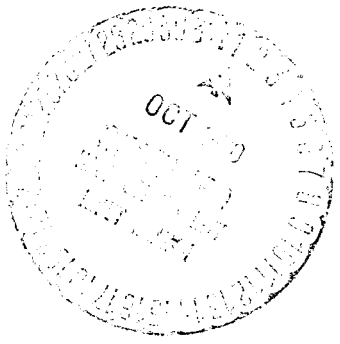
FROM: D. R. Anselmo
W. G. Heffron

ABSTRACT

Based on performance data from Apollo 10 and 11 crews, the analysis in this memorandum shows that, if manual TLI is attempted on Apollo 14, there is a 25 percent chance that a lunar landing cannot be attempted because of insufficient SPS propellant reserves. Of the remaining 75 percent of such missions, 20 per cent can be saved by a corrective burn at TLI + 2 hours and 55 percent can be saved at TLI + 7 hours.

In a late conversation with Mr. H. W. Tindall, MSC, he noted a tentative mission rule for Apollo 14 that a lunar orbital photo mission is acceptable. The data say such a mission is not improbable if manual TLI is attempted.

For Apollo 15 and up, cutoff is automatic and the situation should improve.



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MEMORANDUM FOR FILE

Currently, if Translunar Injection (TLI) has to be done manually on Apollo 14, S-IVB cutoff will be accomplished by the crew. The question addressed in this memorandum is whether the cutoff velocity errors are within the Apollo 14 SPS propellant reserves.

During the burn, the crewmen in the left two seats monitor h, $\dot{h}$ and V on the computer display, and attitude on the FDAI. Comparing these with numbers on a card (calculated pre-mission), they control the attitude of the space vehicle to produce the correct trajectory. Cutoff of the S-IVB is done when the desired inertial velocity is reached (the value is calculated real-time but before TLI ignition). Since the computer display changes only every 2 seconds and cutoff is done by moving the "T-bar" to the left by the leftmost crewman, and since acceleration at TLI is about 42 fps^2, it is difficult to get a very accurate cutoff, even after considerable practice in trainers.

Radial, downrange, and lateral velocity errors can be expected, but only the downrange error is important. The ΔV to correct radial and lateral errors generally decreases as time goes on, but the ΔV to correct downrange errors steadily increases. At TLI + 2 hours, the cost is approximately 3.3 fps for each fps error at TLI cutoff. At TLI + 7 hours, the factor is 5.0 fps/fps.

A reasonable policy is as follows. If the error at cutoff is greater than TBD fps, have the crew quickly perform Transposition, Docking, Extraction and execute a corrective burn at TLI + 2 hours, targeting the burn using the state vector in the Command Module Computer. Two hours is insufficient for MSFN tracking to produce a better estimate than the CMC, but the CMC estimate is probably inaccurate enough that another correction will be required later. But if the TLI cutoff is small enough, no special action is required and the correction burn will occur at the usual times. With MSFN tracking, the targeting will be of superior accuracy. Thus at TLI + 2 hours

propellant usable may not include propellant budgeted for a "normal" MCC (which is 33 fps), while at TLI + 7 hours it may.

Crew performance data for the Apollo 14 crew is not available, but data from Apollo 10-11 crews is, and is plotted on the attached chart as a probability distribution. Scales also show the ΔV required at TLI + 2 hours and TLI + 7 hours and the contingency ΔV that would remain for a 9-day mission.

The contingency ΔV available, shown for a correction at TLI + 2 hours, actually increases slightly before decreasing for increasing TLI cutoff errors. The reason for this is that the nominal mission employs a 73 fps hybrid maneuver at TLI + 24 hours which transfers the vehicle from the free return trajectory to a DPS abortable non-free return trajectory. If a correction is made at TLI + 2 hours the trajectory would be corrected to the post-hybrid maneuver conditions so that the hybrid maneuver is effectively reduced and combined with the correction for the cutoff error, the net result being a reduction in total mission required ΔV.

The Apollo 14 mission duration is nomially nine days. For the 9-day mission the end-of-mission contingency ΔV available for weather avoidance is 318 fps. By extending the return time of flight by 24 hours and employing a 10-day mission, contingency ΔV reserves increase to about 600 fps. Relaxation of the 40 degree maximum return inclination constraint would increase reserves to about 800 fps for the 10-day mission. If the 600 fps LM rescue allowance is retained, the ΔV available beyond requirements to correct an off nominal TLI is approximately one-half of the remainder or 1/2 (800-600) = 100 fps, the one-half factor being due to the heavier weight post-TLI compared to end-of-mission weight. The curves show that 55 percent of the time the mission could be continued by making a corrective maneuver at TLI + 7 hours. The probability could be extended to 75 percent by making the maneuver at TLI + 2 hours. To obtain a further increase the LM rescue allowance would have to be reduced. Note that these probabilities mean also that 45 percent of the time the corrective burn must be done quickly (TLI + 2 hours), and even so 25 percent of the missions cannot be continued to landing.

For Apollo 14 and subsequent, a new computer program will automatically generate a cutoff signal based on velocity magnitude (the same number now used for manual cutoff). Down-range errors will then largely be elimated and a TLI + 2 hour

burn will be improbable. There is a possibility that this routine could be added for Apollo 14, but such action would require a remake of the Memory Modules for the CMC; the program for Apollo 14 has already been released for manufacture.

D. R. Anselmo

W. G. Heffron

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Attachment

PROBABILITY WITH MANUAL TLI CUTOFF